



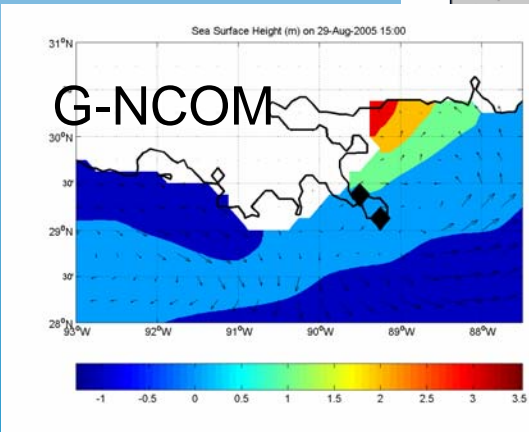
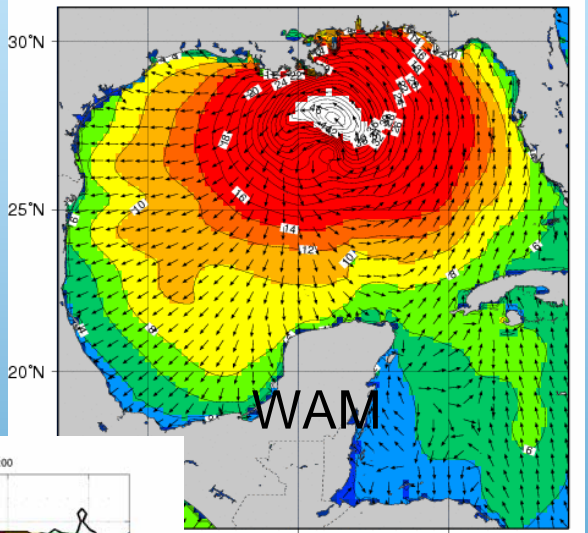
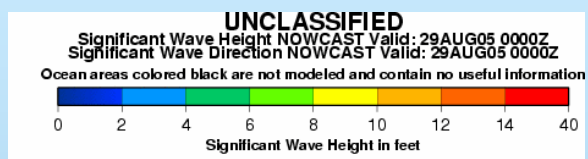
# The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)

Frank L. Bub,  
Head, Ocean Modeling  
Division (N33)

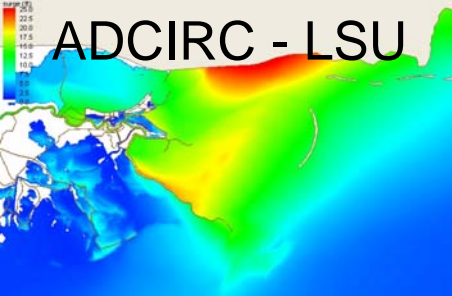
[frank.bub@navy.mil](mailto:frank.bub@navy.mil)

228-688-4758

<https://www.navo.navy.mil/ops.htm>



WAVE Model (WAM)  
/AL OCEANOGRAPHIC OFFICE  
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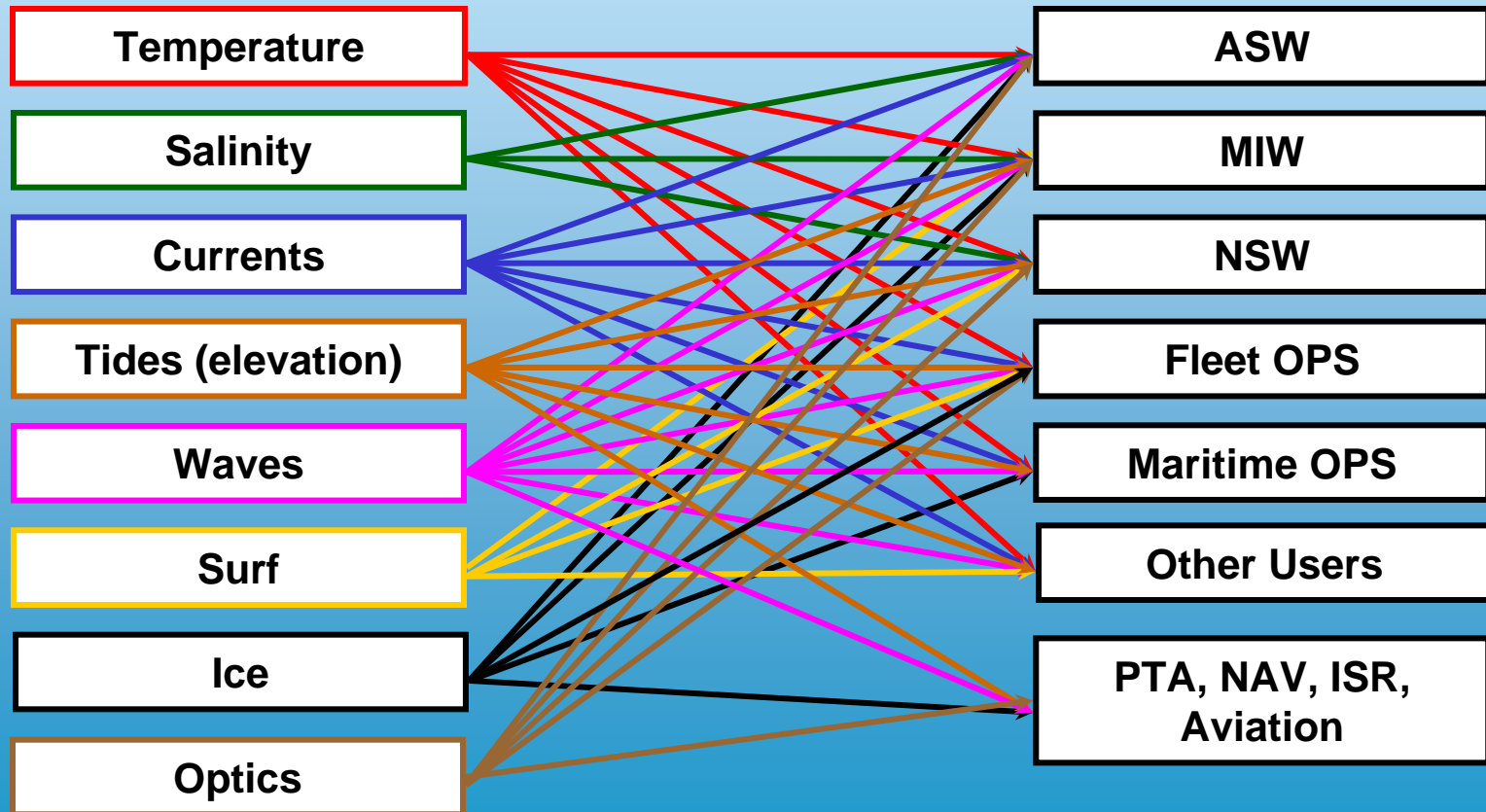
Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>DEC 2005</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2005 to 00-00-2005</b>	
4. TITLE AND SUBTITLE <b>The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
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13. SUPPLEMENTARY NOTES <b>9th HYCOM Consortium Meeting, Dec 6-8, 2005, RSMAS, Miami, FL</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>35</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# Basic Product Suite Mapped to Navy Lines of Operation



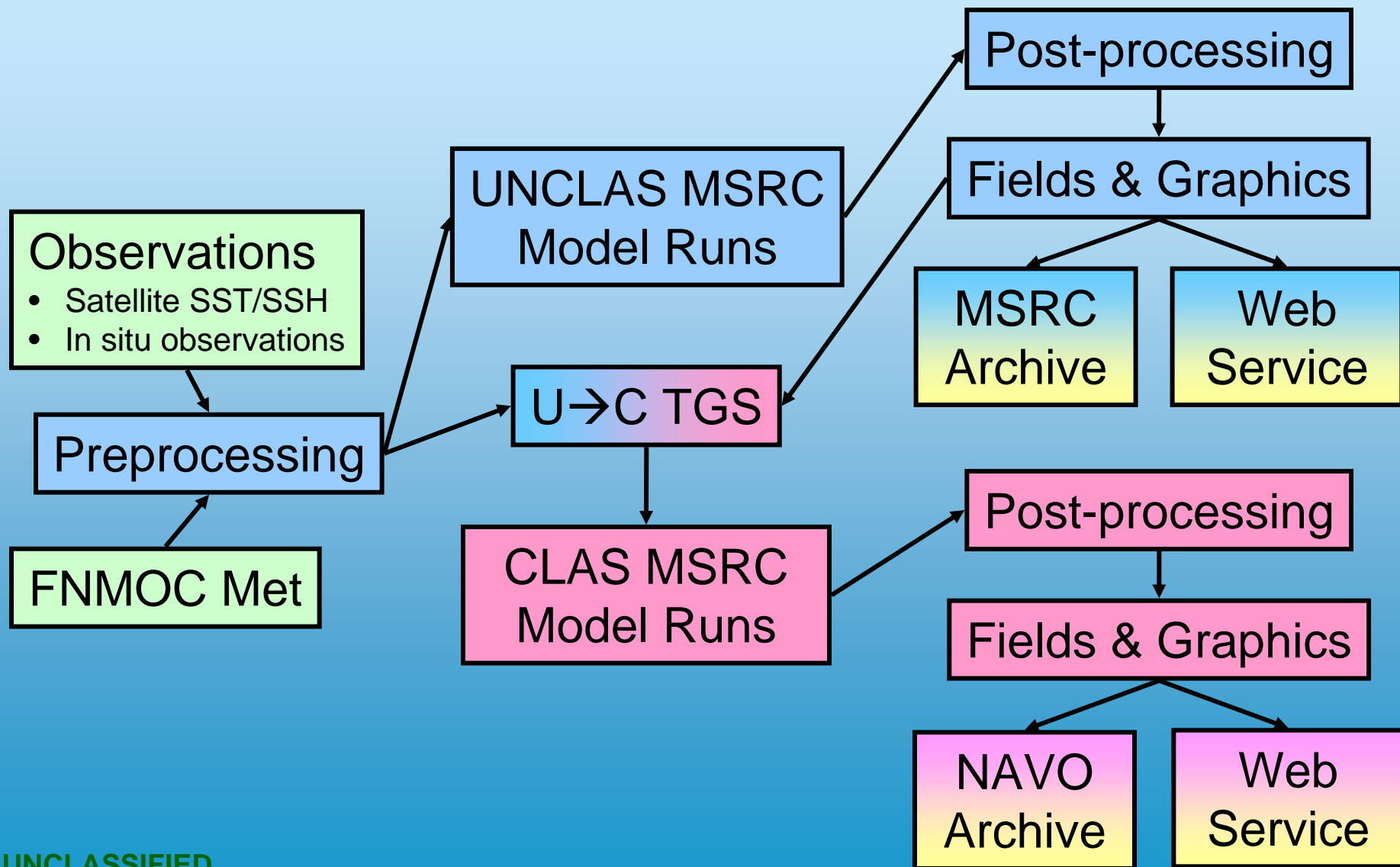
*NAVOCEANO's business is to*

- Collect or acquire observations & information for the....
  - Analysis and prediction of....
- Currents, Temperature, Salinity, Sound Speed, Waves, & Optics.



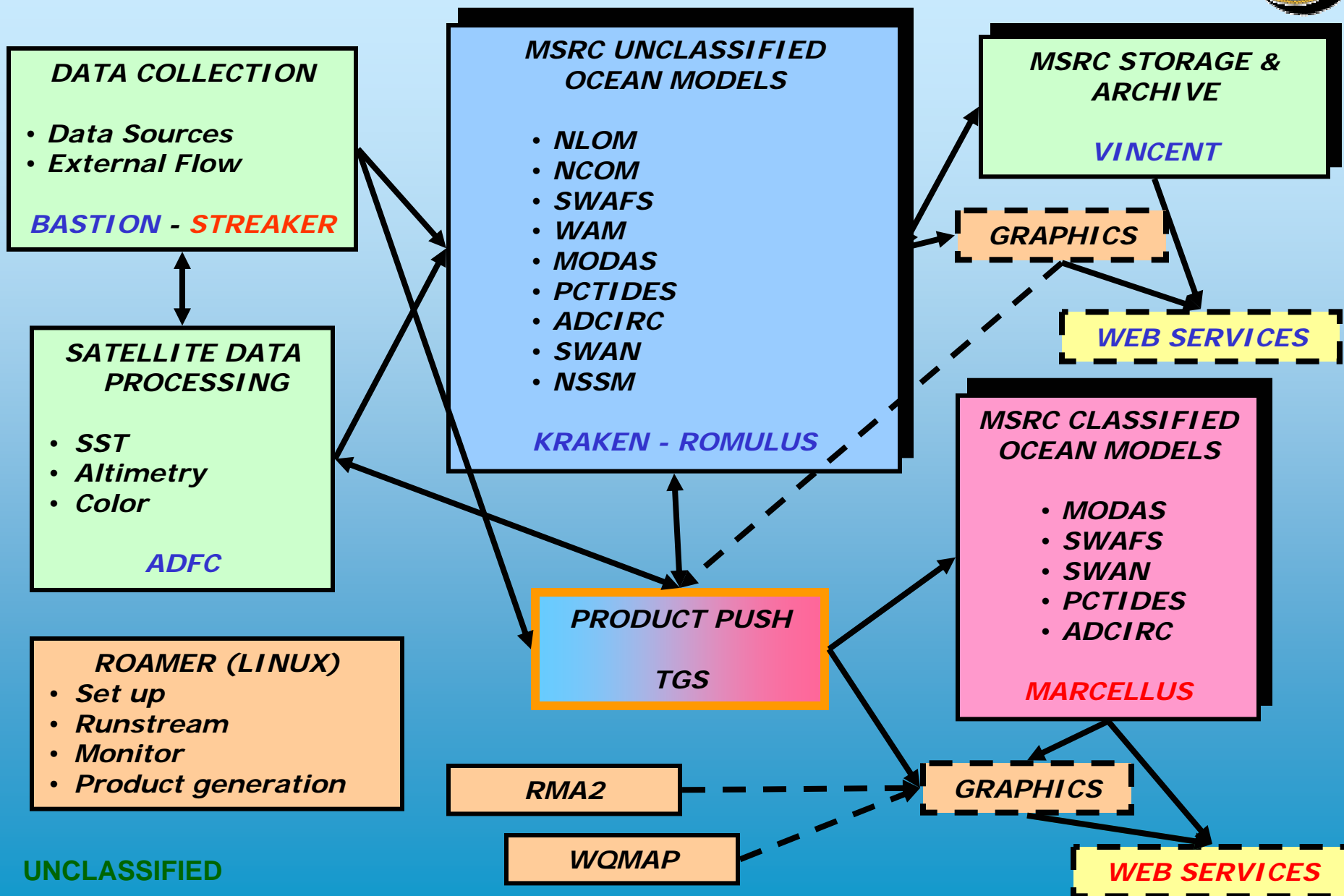
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# NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



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# NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



# NAVOCEANO MSRC Assets - CY2005



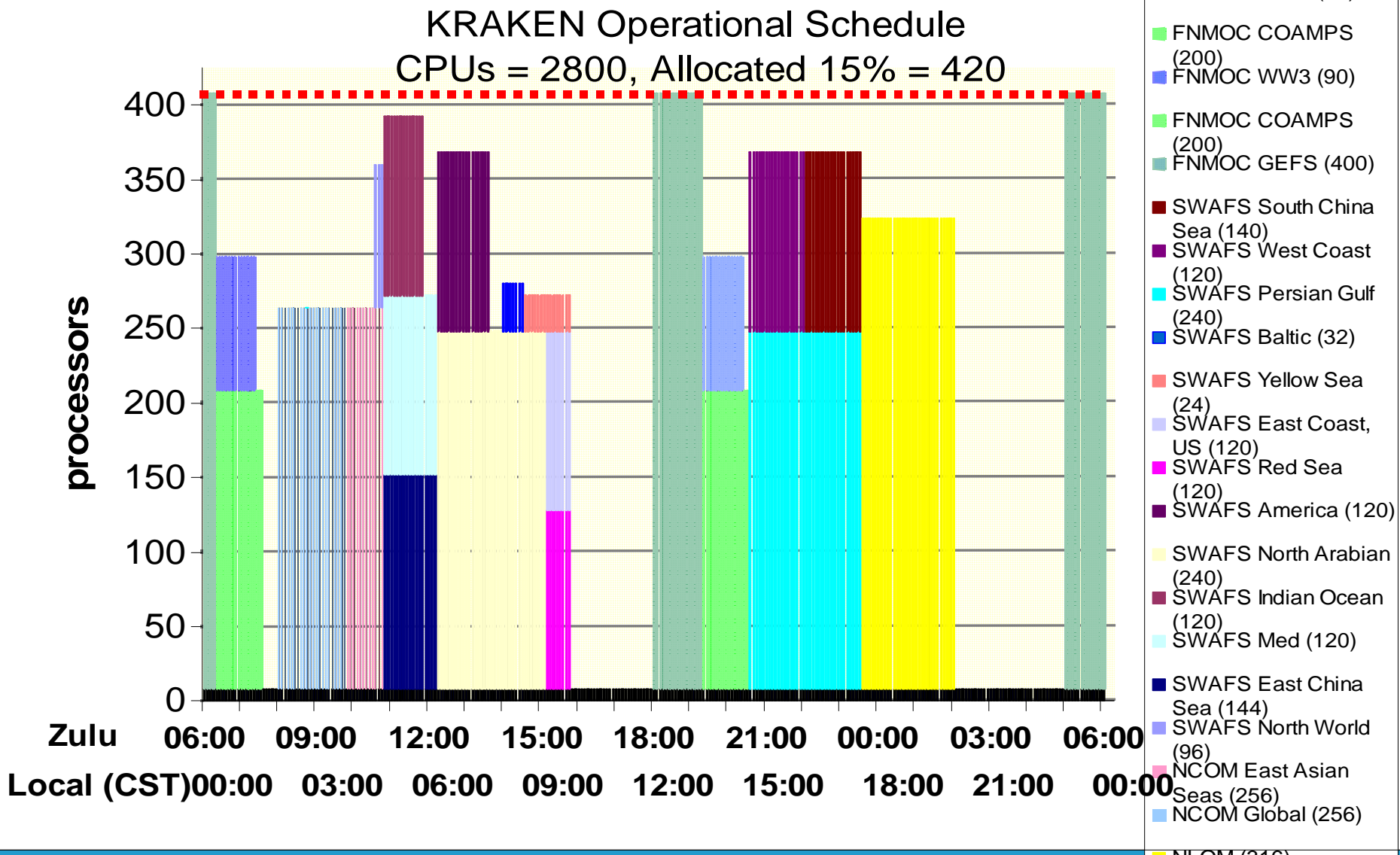
SYSTEM		Speed	CPUS		15%	GFLOPS *			
NAME	MODEL	MHZ	TOTAL	AVBL	CNMOC	PER cpu	AVBL	CNMOC	CLAS
<b>2005</b>									
<b>Kraken</b>	IBM Power-4+	<b>1,700</b>	2,944	2,832	<b>425</b>	6.8	19,258	<b>2,889</b>	U
<b>Romulus</b>	IBM Power-4+	<b>1,700</b>	512	464	<b>70</b>	6.8	3,155	<b>473</b>	U
<b>Marcellus</b>	IBM Power-4	<b>1,300</b>	<b>1,408</b>	<b>1,328</b>	<b>199</b>	<b>5.2</b>	<b>6,906</b>	<b>1,036</b>	<b>C</b>
<b>2004</b>									
<b>Habu</b>	IBM SP Power 3	<b>375</b>	976	928	<b>139</b>	1.5	1,392	<b>209</b>	U
<b>Poseidon</b>	Cray SV-1EX	<b>500</b>	64	64	<b>10</b>	2.0	128	<b>19</b>	U
<b>Camille</b>	Cray SV1	<b>300</b>	<b>32</b>	<b>32</b>	<b>5</b>	<b>1.2</b>	<b>38</b>	<b>6</b>	<b>C</b>
<b>Butch</b>	Sun F1200	<b>900</b>	<b>8</b>	<b>8</b>	<b>1</b>	<b>3.6</b>	<b>29</b>	<b>4</b>	<b>C</b>
		<b>TOTALS</b>	<b>End 2004</b>		<b>354</b>		<b>8,493</b>	<b>1,274</b>	
			<b>End 2005</b>		<b>694</b>	<b>+196%</b>	<b>29,318</b>	<b>4,398</b>	<b>+345%</b>

\* A **gigaflop** is defined as a billion ( $10^9$ ) Floating Point Operations. This is calculated by multiplying the speed of a processor (CPU) times the number of CPUs used, times the wall clock time in seconds, to determine model “cycles” required. This is multiplied by 4 flops/cycle.

**UNCLASSIFIED**

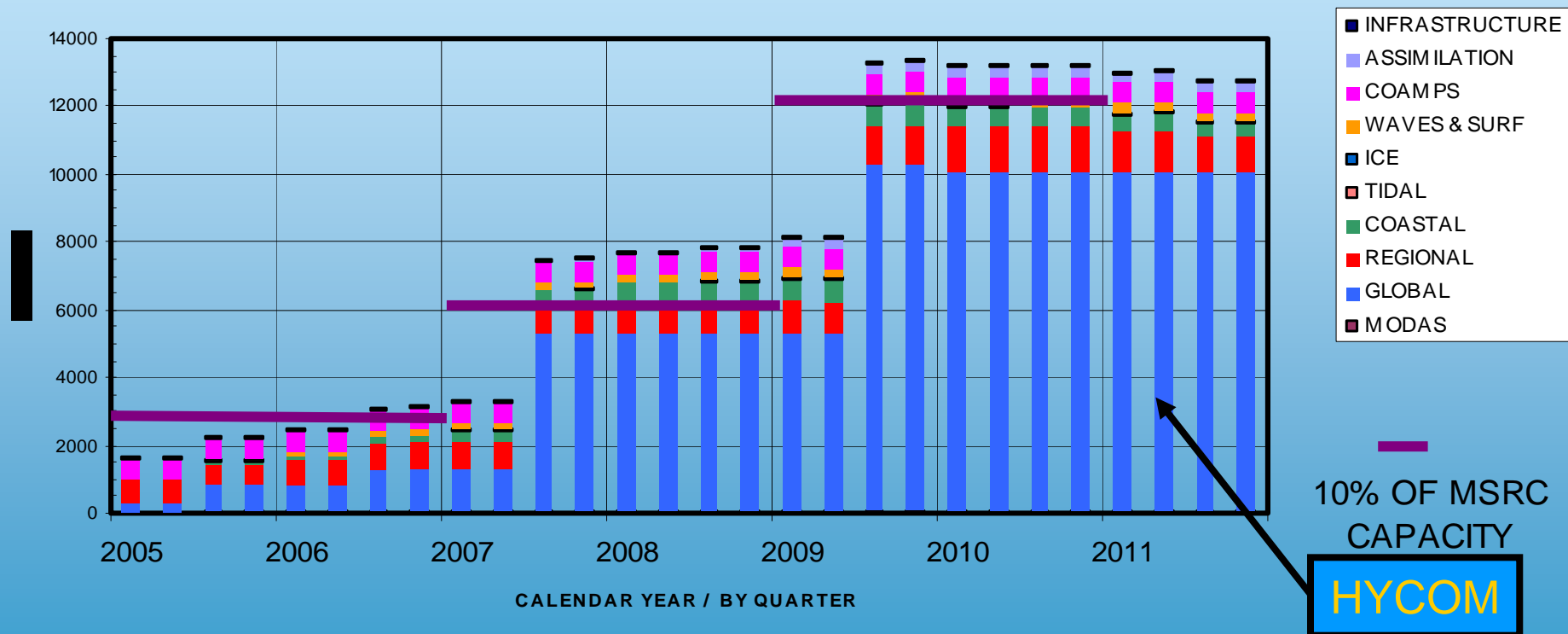
# NAVOCEANO MSRC Schedule

## Kraken – AUGUST 2005



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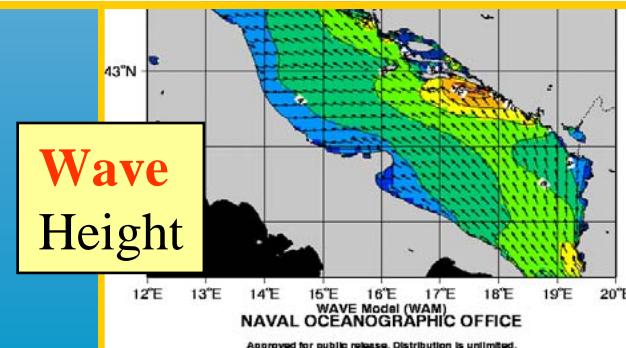
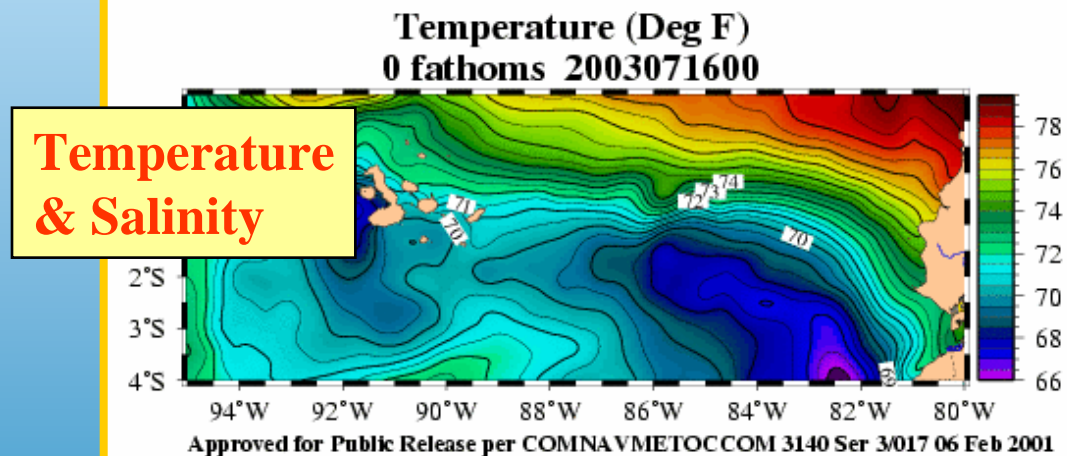
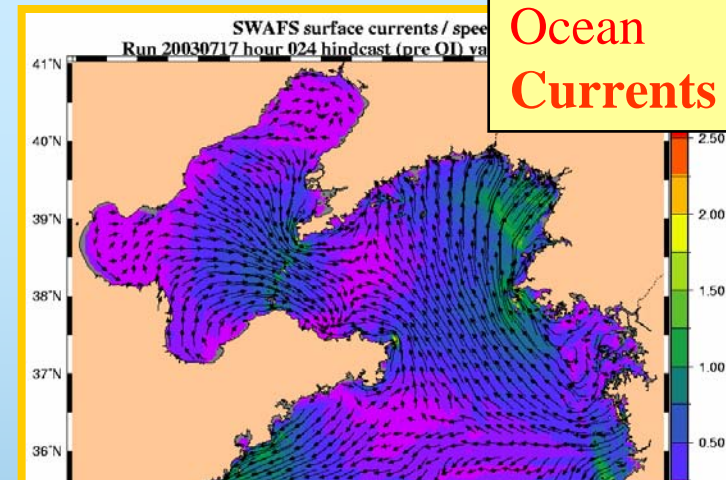
# NAVOCEANO MSRC Requirements through CY2011 in gigaflops (billions of floating point operations)



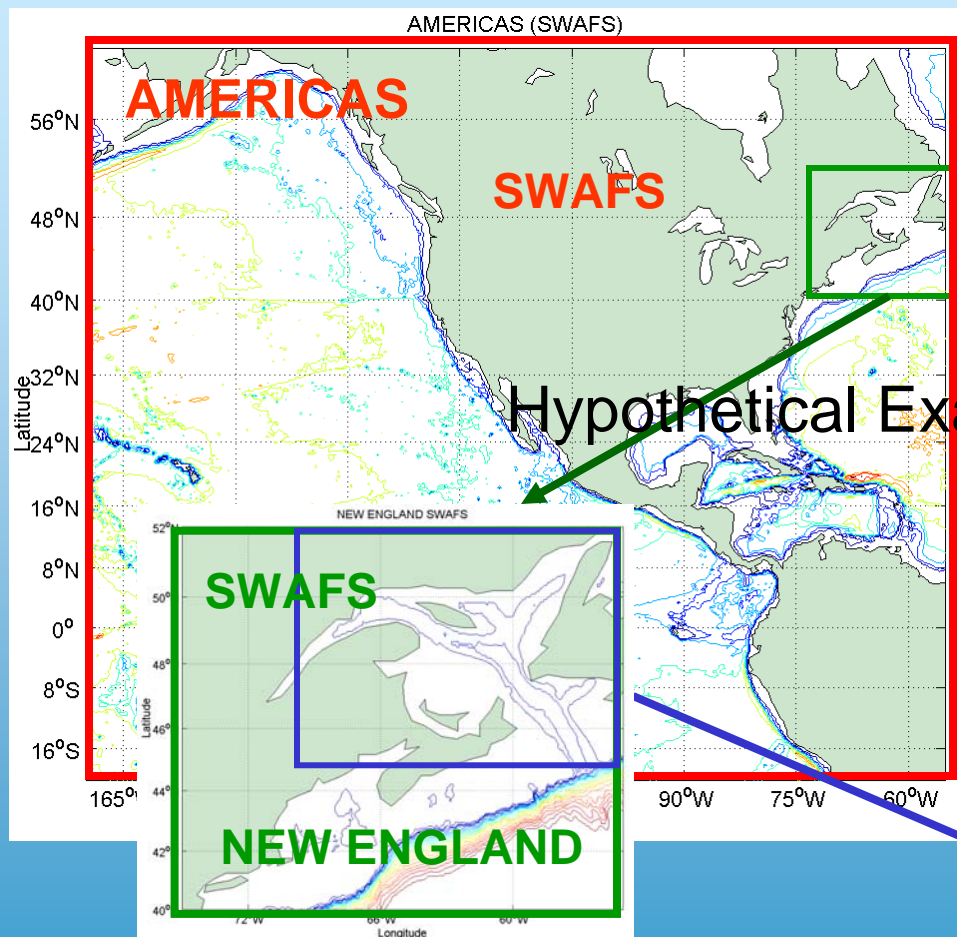


# Operational Modeling distinct from R&D Modeling

- Daily Product Generation  
(focus on Navy Fleet)
- Products support real  
needs, operations
- Reliability expected
  - Timely
  - Accurate



# To Achieve Needed Resolutions, We Nest Boundary & Initial Conditions



## Global NCOM

- ~14km resolution
- 2.6 mil gridpoints

## AMERICAS (2:1)

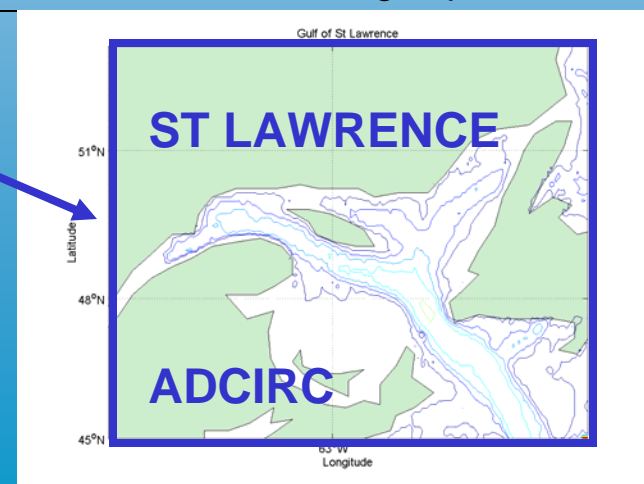
- ~8km resolution
- 1.4 mil grid points

## NEW ENGLAND (3:1)

- ~3km resolution (3:1)
- 230K grid points

## ST LAWRENCE (3:1)

- ~1km resolution
- 820K grid points



Notes: Recent Arabian Gulf SWAN – 3 WAM & 3 SWAN nests (9 hr computation time)

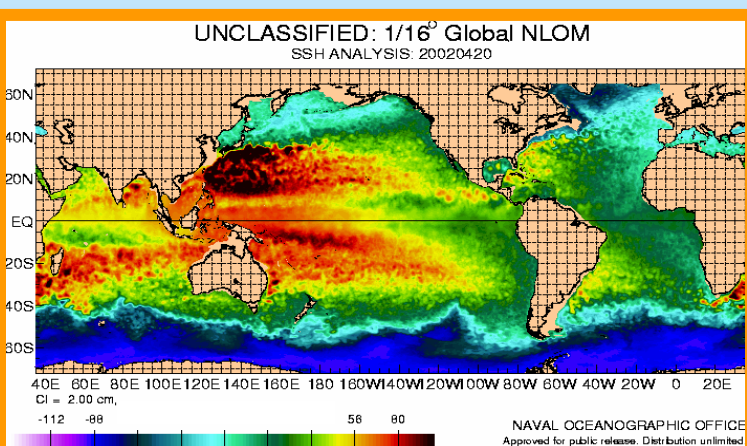
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# Global

# Regional

# Local



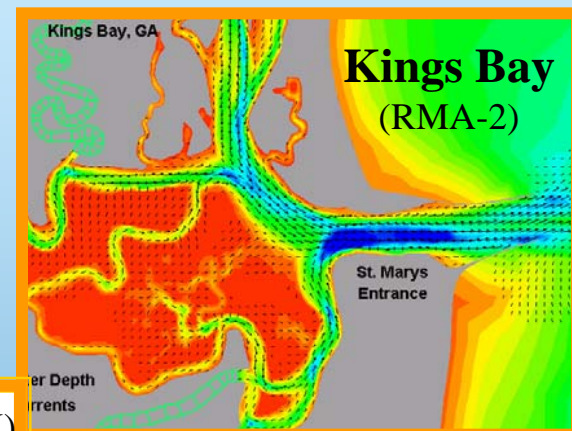
## Global Deep Ocean Models:

- Regional models boundary conditions
- Transit planning
- Filling gaps

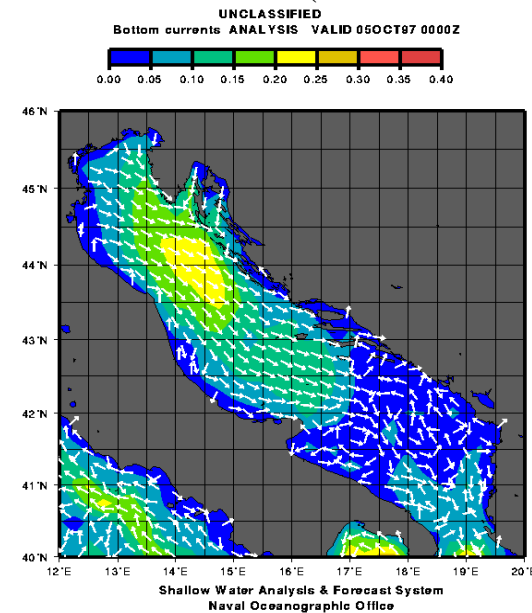
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## Regional Littoral Models:

- High-resolution processes
- Theatre Operations



## Adriatic Sea (SWAFS-POM)



## Coastal - Local - Estuary Models:

- Coastal operations
- NSW
- MIW

# Ocean Models at NAVOCEANO



## Global Circulation Models

- NLOM / G-NCOM

## 3-D Coastal Circ Models

- SWAFS --> Rgnl-NCOM (FY07)
- EAS NCOM (FY06)

## Vertical Profile (T,S) Model

- MODAS

## Wave Models

- WAM
- ST-Wave --> SWAN
- Navy Std Surf Model
- Delft3D SWAN/FLOW (FY06?)

## 2-D Coastal Circ Models

- WQMAP \*
- HydroMap \*
- RMA-2
- ADCIRC (FY06)\*
- CU-Tides --> PC-Tides (FY05)

\* 3D Capability also





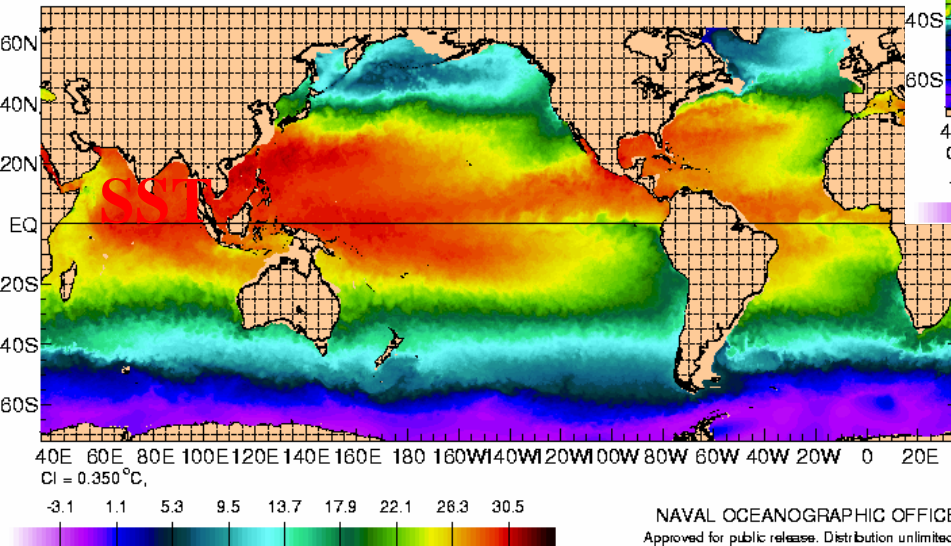
Global

Regional

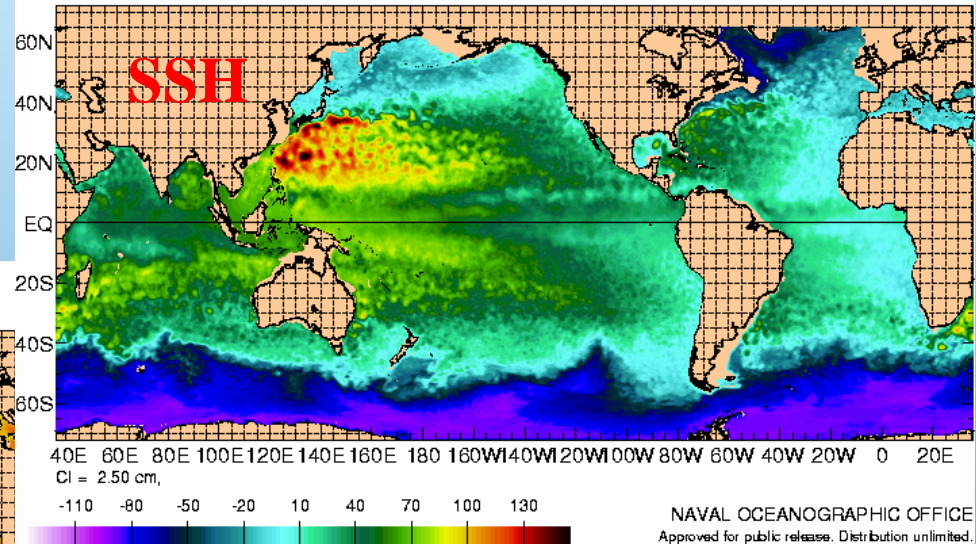
Local

# NAVY LAYERED OCEAN MODEL NLOM

UNCLASSIFIED: 1/16° Global NLOM  
SST ANALYSIS: 20030716



UNCLASSIFIED: 1/16° Global NLOM  
SSH ANALYSIS: 20030716



- 1/16 --> 1/32 degree resolution
- SSH for Global Circulation Models
- 4 --> 2 nm resolution
- 200m or deeper water
- 7 vertical layers
- For position of fronts and eddies
- Sea Surface Temp, Salinity & Height
- NOT VALIDATED FOR CURRENTS

1/32 deg (~2.5 km /1.3 nm)

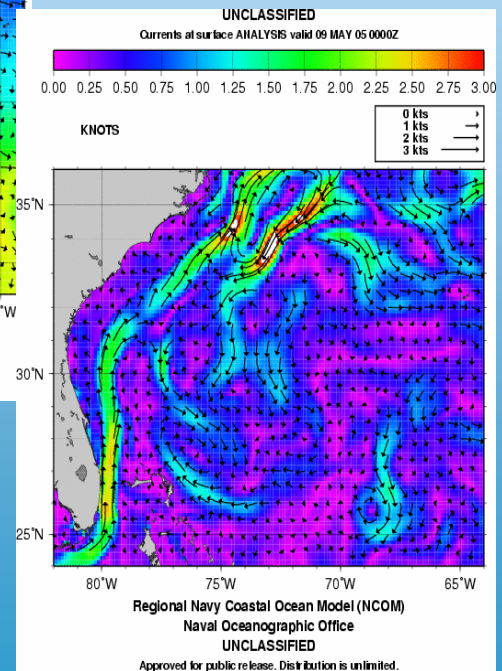
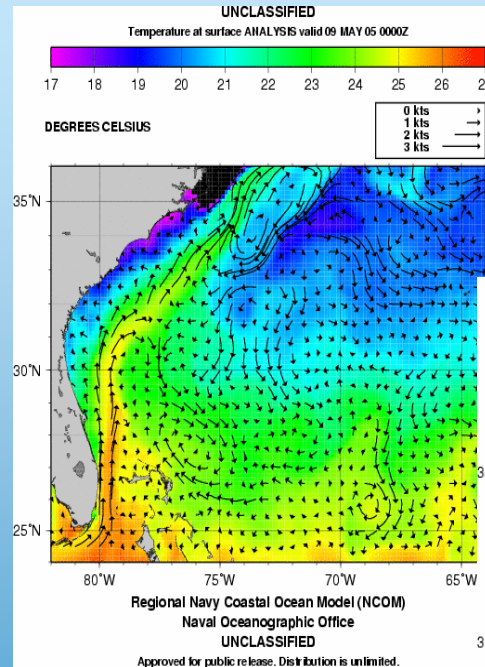
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## GLOBAL NAVY COASTAL OCEAN MODEL G-NCOM

- POM-based model
- 3D Forecasts of Temperature, Salinity, Currents, Elevation
- Resolution 1/8 deg
- 42 vertical layers
- Forecast to 72hr @ 3hr increments
- FNMOC NOGAPS atmosphere
- Assimilates SSTemp / SSHeight
- Will assimilate profiles – 2006 (NCODA)
- Deep water – mesoscale processes
- Tides from OSU (Egbert) model
- Lateral boundary conditions for higher resolution nests (SWAFS / regional NCOM)

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1/8 deg (~10 km / 5 nm)



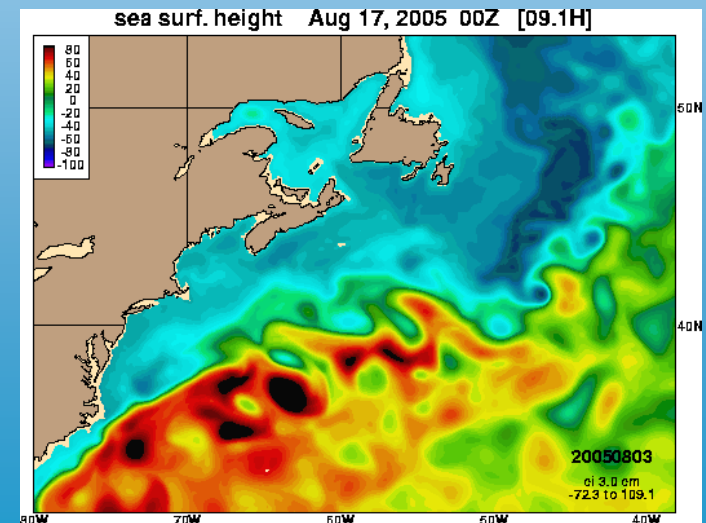
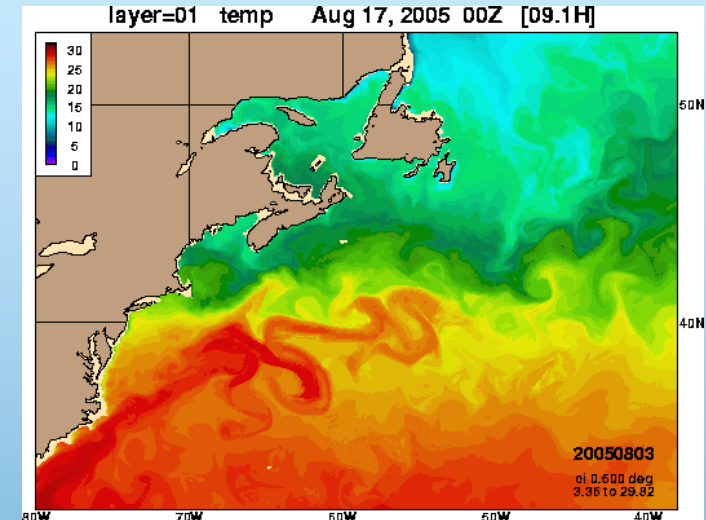
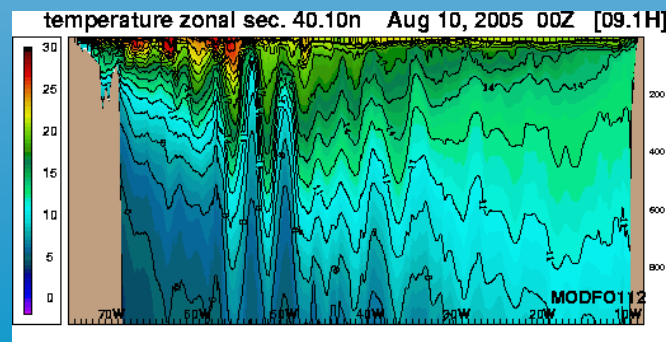
Global

Regional

Local

## HYBRID COORDINATE OCEAN MODEL HYCOM

- Next generation dynamic model
- **NOPP Consortium** – NRL lead, U Miami, Los Alamos, French, NOAA/AOML, etc.
- **Temperature, Salinity, Currents, Elevation**
- Initial global resolution 1/12 deg (6.5 km / 3.5 nm)
- Final resolution **1/24 deg** (3.8 km / 1.8 nm)
- 40+ vertical layers
- Pressure, depth, sigma coordinates as needed
- Forecast to **120hr**
- **Assimilates** SST / SSH / profile data - NCODA
- Global and regional model replacements
- Global service
- ESMF backbone



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# NLOM - Navy Layered Ocean Model

## G-NCOM - Global Navy Coastal Ocean Model

## G-HYCOM - Global Hybrid Coordinate Ocean Model



GLOBAL		YEAR	2005	2006	2007	2008	2009	2010	2011
NLOM 1/16 degree	U	GLOBAL							
NLOM 1/32 degree	U	GLOBAL						-->HYCOM	
G-NCOM 1/8 degree	U	GLOBAL						-->HYCOM	
G-HYCOM 1/12 degree	U	GLOBAL							
G-HYCOM 1/24 degree	U	GLOBAL							
MSRC		gigaflops	735	1235	5235	5235	10,235	10,000	10,000
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- Global models will **dominate processing** requirements.
  - Until 1/24-degree HYCOM in CY2011, the main purpose is to **provide boundary conditions** for the regional models.
- HYCOM** will begin to run on MSRC in an **R&D model in CY2005** & a 1/12-degree global HYCOM will begin **OPEVAL testing in CY2007**.
  - We leap to a **10,000-gigaflop** requirement in CY2009 as we move to the 1/24-degree HYCOM.

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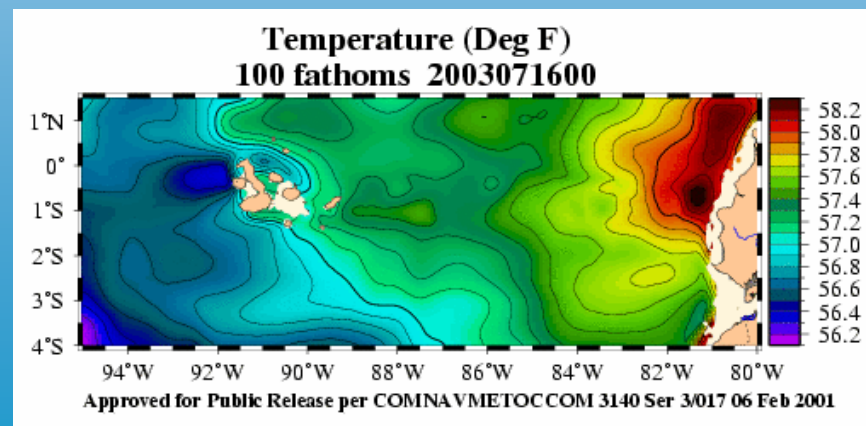
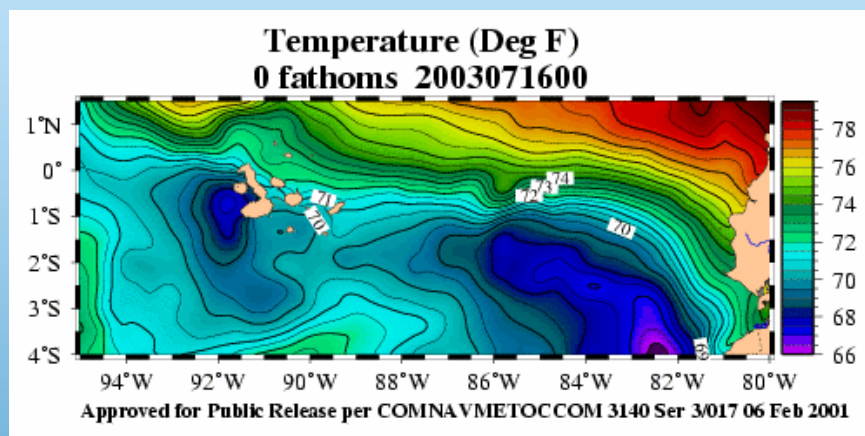
Global

Regional

Local

## MODULAR OCEAN DATA ASSIMILATION SYSTEM - MODAS

- Relocatable, variable resolution
- Statistical Analysis Model for:
  - Temperature
  - Salinity
  - Derive quantities  
(sound speed, etc.)
- Optimum Interpolation of:
  - MCSSTs
  - Altimetry
  - Gridded climatology (T,S)
  - Near-real time XBTs
- 3-D Sound Speed
  - Acoustic ranging, sensor placement
  - GF MPL
  - PC-IMAT / NITES



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# MODAS- Modular Ocean Data Assimilation System



MODAS		YEAR	2005	2006	2007	2008	2009	2010	2011
2D/3D	U	GLOBAL						-->HYCOM	
2.1 (HEAVY)	U	10 AREAS							
2.1 (HEAVY)	C	20 AREAS							
2.2 (HEAVY)	U	10 AREAS							
2.2 (HEAVY)	C	20 AREAS							
NEXT (DYNAMIC)	C	30 AREAS							
3.0 (NEXT GENERATION)	C	30 AREAS							
MSRC		gigaflops	62	62	62	81	85	55	45
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- MODAS upgrades:
  - Now - reduce the number of domains to 15-20 at 1/12-degree resolution.
  - MODAS-NEXT - insertion of SWAFS/NCOM fields into the MODAS framework as forecasts
  - MODAS 3.0 - a totally new assimilative scheme for 2D/3D



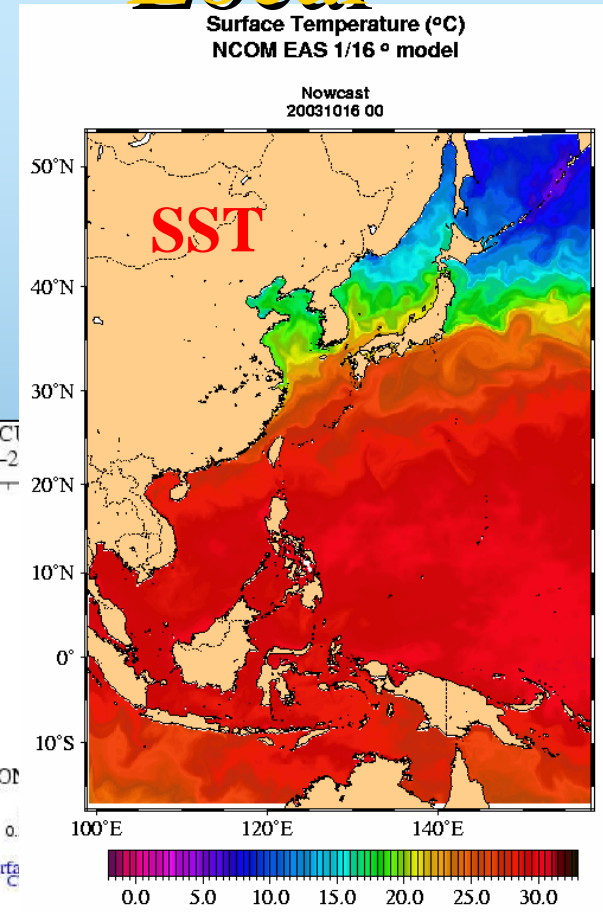
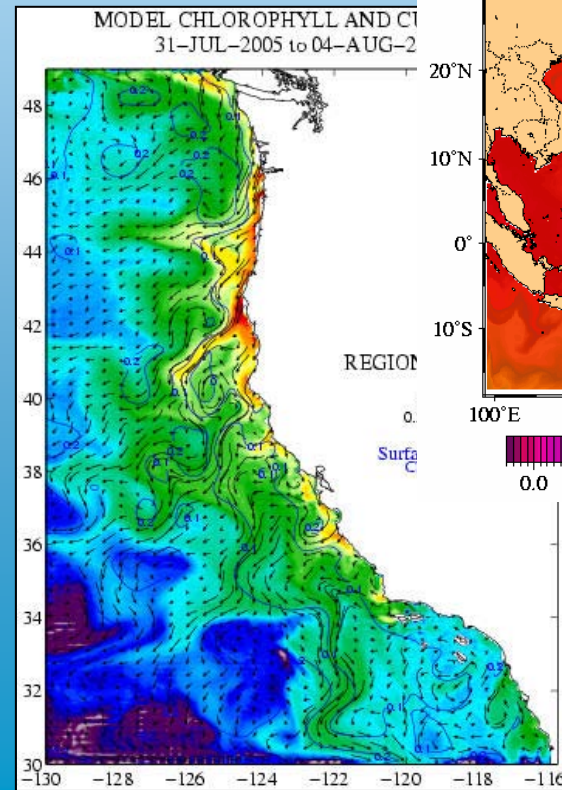
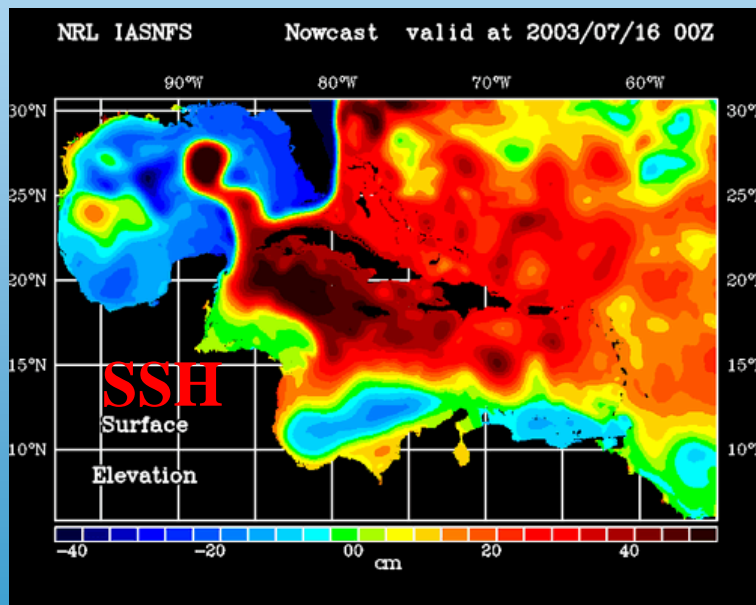
Global

Regional

Local

## Regional NCOMs

- East Asian Seas (EAS) - 1/16 deg
- Intra-Americas Seas (IAS) - 1/24 deg
- California Coastal Current – 1/12 deg



- Relocatable Nested Regional NCOM – FY07

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Global

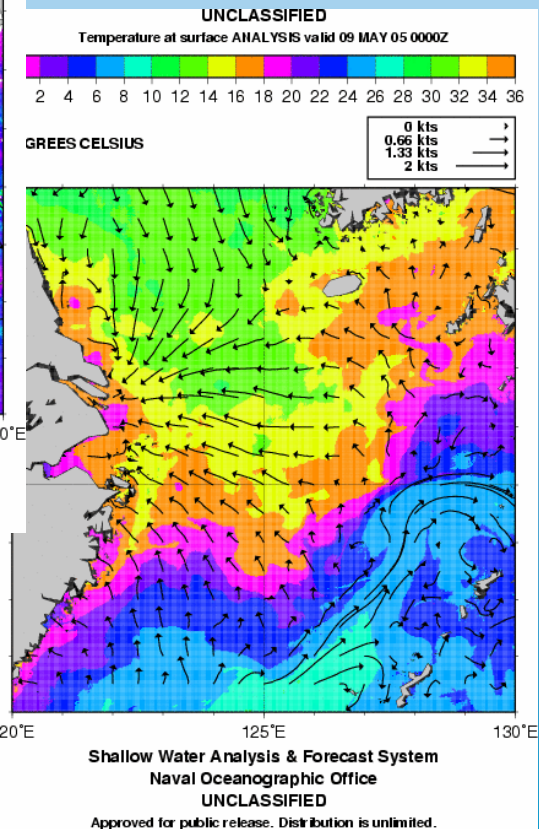
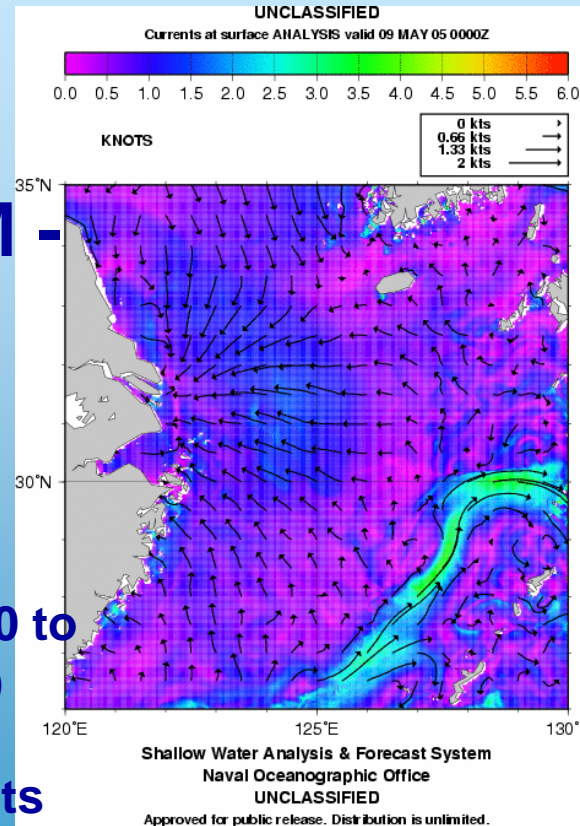
Regional

Local

# SHALLOW WATER ANALYSIS & FORECAST SYSTEM - SWAFS

- POM-based model
- 3D Forecasts
- **Currents, T-S, Elevation**
- Resolution varies by region (1/50 to 1/4 deg (0.5 to 24km / 1 to 15 nm))
- 27 to 47 vertical layers
- Forecast to 48hr @ 1hr increments
- Assimilates data from satellites (SST, SSH), *insitu* obs (XBTs, CTDs, floats, buoys), IHO tides

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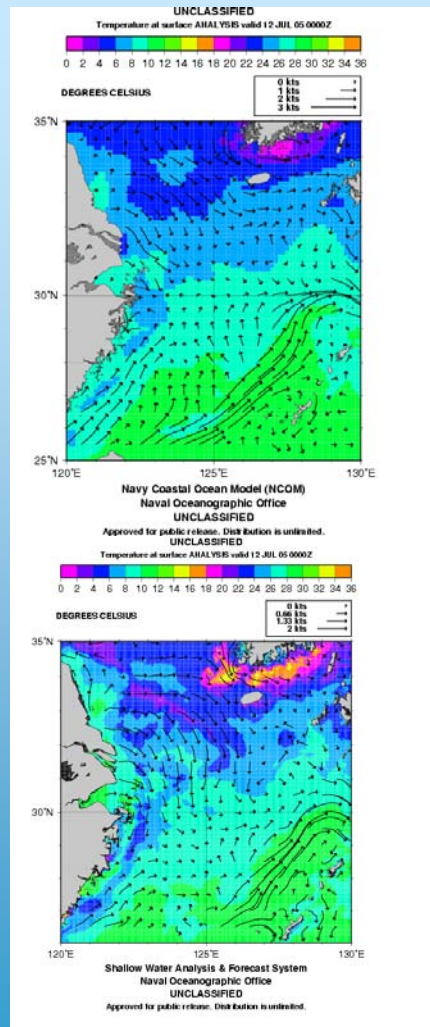


# GNCOM and SWAFS Surface Currents over Temperature

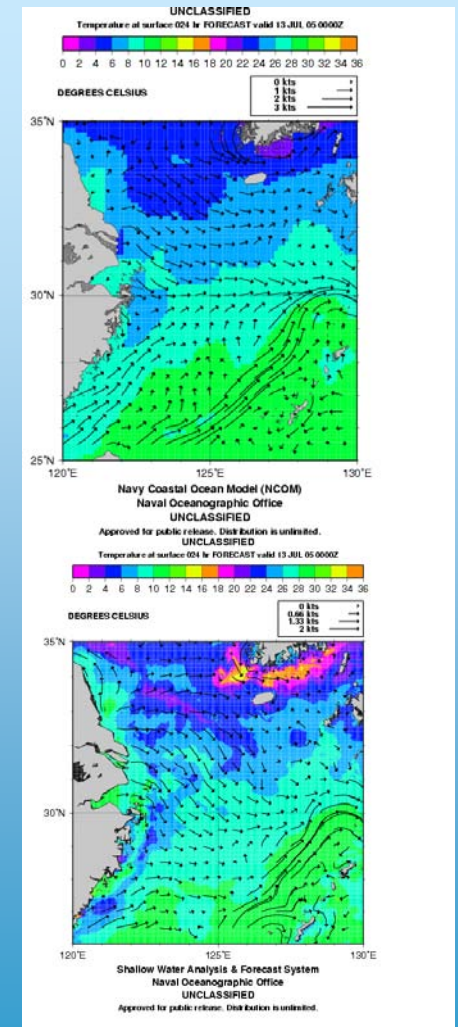
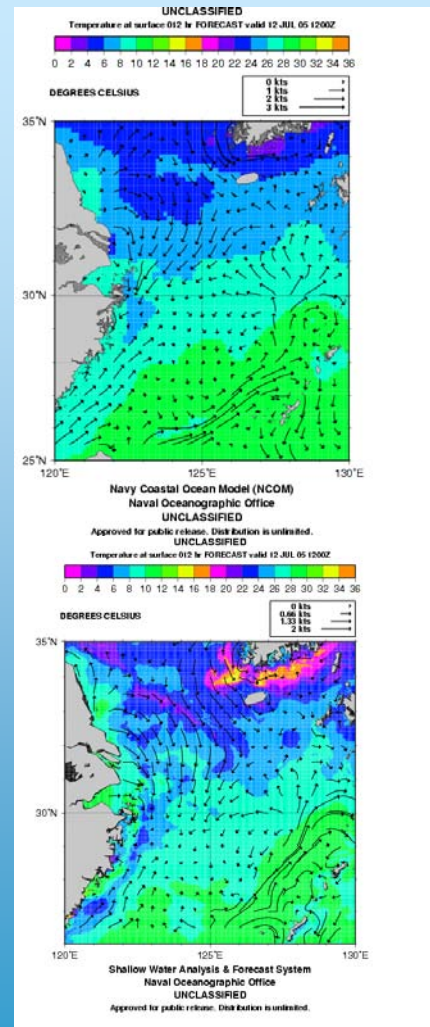
## Runs 00Z 12JUL05 taus 00 – 12 – 24 hrs



GNCOM



SWAFS



Notes: Model similarities and differences, SWAFS vectors 150% larger, GNCOM 1/8 deg and SWAFS 1/50.

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# SWAFS - Shallow Water Analysis and Forecast System

## R-NCOM - Regional / Relocatable Navy Coastal Ocean Model

## R-HYCOM - Regional Hybrid Coordinate Ocean Model

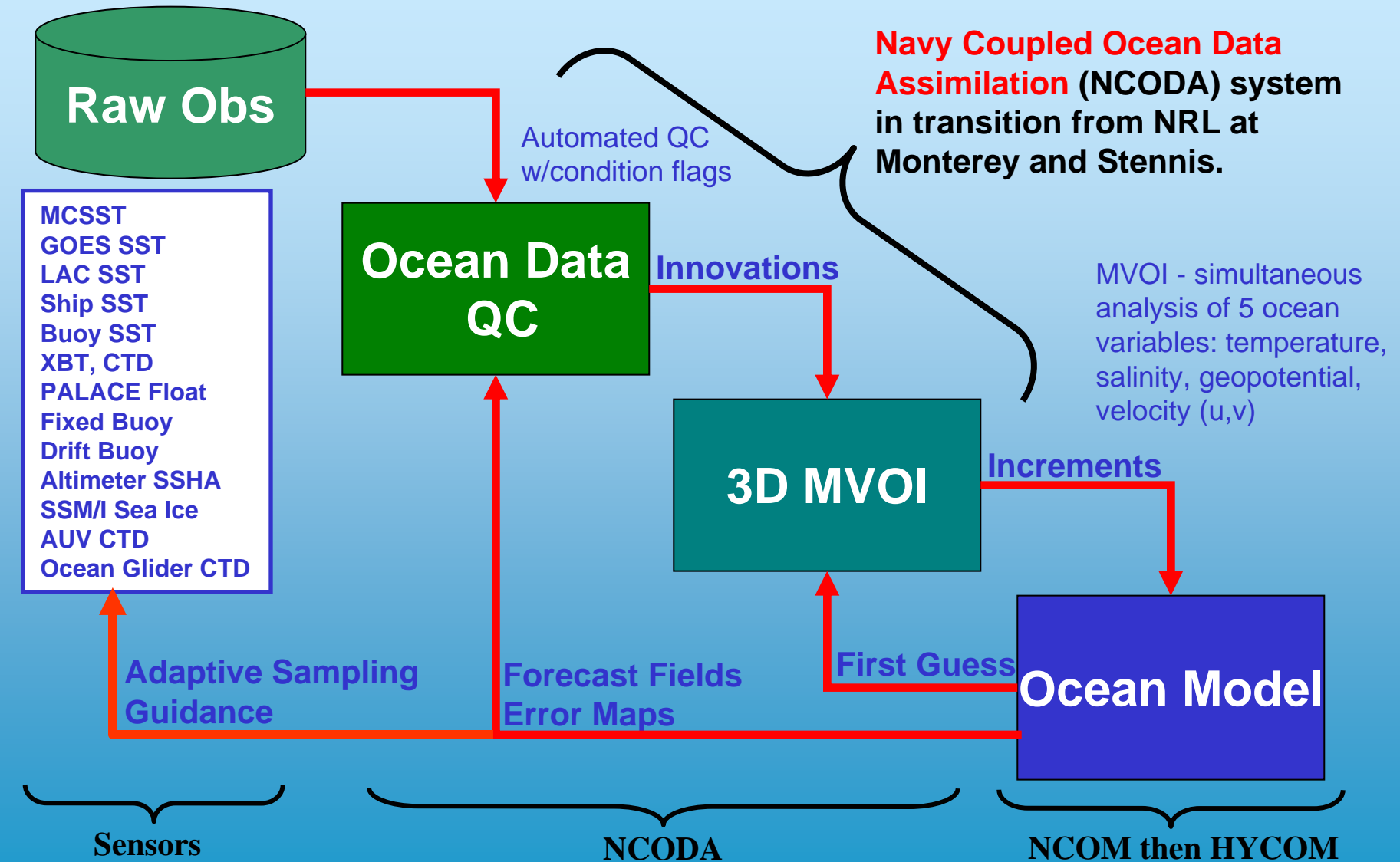


REGIONAL		YEAR	2005	2006	2007	2008	2009	2010	2011
SWAFS	U	9 NESTS				-->R-NCOM			
SWAFS	C	3 NESTS					-->R-NCOM		
R-NCOM 1/16 - 1/24	U	7 AREAS							
R-NCOM - HIRES 1/50	U	6 AREAS						-->R-HYCOM	
R-NCOM - HIRES 1/50	C	3 AREAS						-->R-HYCOM	
R-HYCOM HIRES 1/50	U	Global							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- Currently **SWAFS** uses most of our resources @ 12 domains ~600-gigaflops
- The East Asian Seas (EAS-NCOM) starts the transition to regional NCOM models
  - NRL is developing a “**relocatable**” **NCOM** package that can nest down from G-NCOM to required resolutions fairly rapidly (CY2006).
  - ~7 medium resolution R-NCOM areas
  - ~6 small, high resolution (1/50-deg) domains of Navy interest.
  - ~3 rapidly implemented, very high-res, short-lived classified domains for special operations.
- When the **1/24-degree HYCOM** is operational by CY2011
  - Many of the NCOM regional domains will no longer be needed.
  - Will run some high to very high-resolution HYCOM domains for specific Navy-interest areas

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# Real-Time Profile Assimilation w/NCODA (FY06)



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# Data Assimilation & Infrastructure



ASSIMILATION		YEAR	2005	2006	2007	2008	2009	2010	2011
NCODA MVOI	U	GLOBAL							
NCODA MVOI	C	GLOBAL							
MSRC		gigaflops	15	30	30	30	300	300	300
INFRASTRUCTURE		YEAR	2005	2006	2007	2008	2009	2010	2011
GRAPHICS (MOGS)	U								
ARCHIVE (MDDAS)	U								
DISTRIBUTION (MDDDS)	U								
QC - NCODA	U								
ESMF (BEI)	U								
MSRC		gigaflops	43	83	75	75	75	75	75
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- **NCODA** upgrade in 2009 goes to 4DVAR
  - NCODA includes an observation QC package
- MOGS, MDDAS, MDDDS all NAVO internal pre- & post-processing on MSRC
- Earth System Modeling Framework (**ESMF**) will be information backbone for all models

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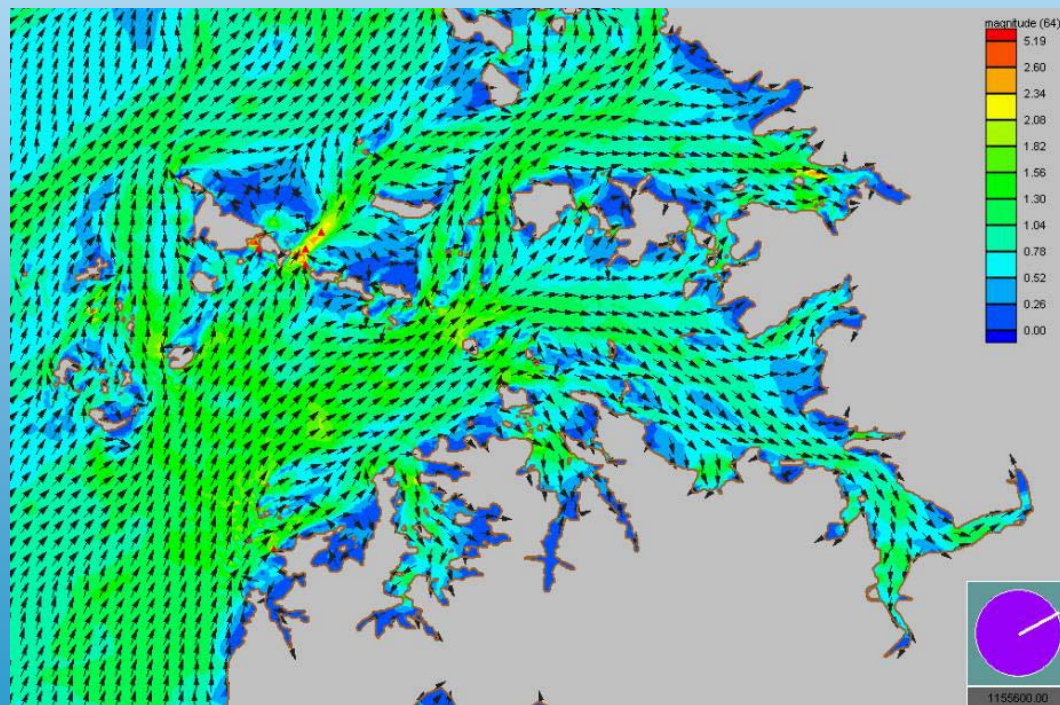
## ADVANCED CIRCULATION MODEL - ADCIRC

### 2D BAROTROPIC ADCIRC

- New generation finite element model
- Consortium model (NRL, Notre Dame, UNC, NOAA NOS, ...)
- Coastal currents, elevation
- Rapid deployment
- Inputs winds at each node
- Fully tidal
- Run on Linux or MSRC
- FY06 (NRL)

### 3D BAROCLINIC ADCIRC

- Coastal ASW tool
- T, S, currents, elevations
- FY08



Global

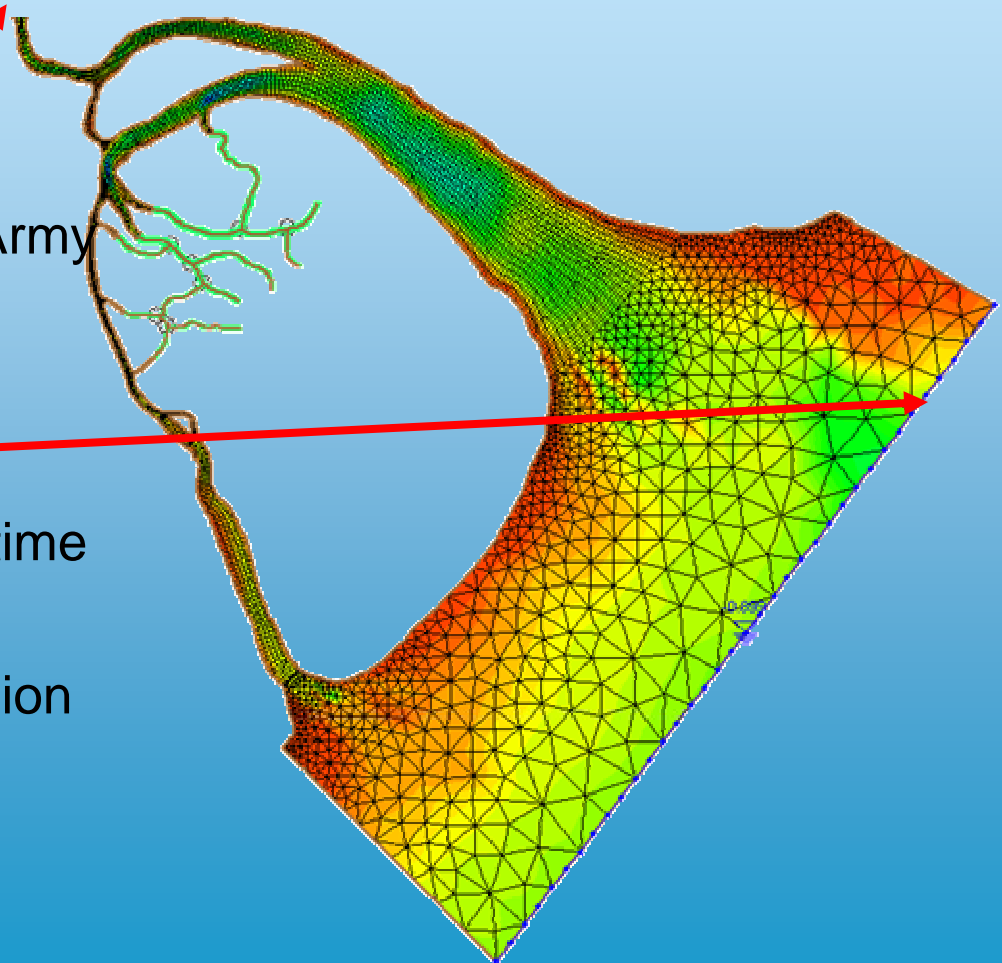
Regional

Local



## RMA2 - River/Estuary 2D Model

- RMA2 Finite Element Model (US Army Corps of Engineers)
- **Forced** with river runoff & tidal constituents
- **Forecast** tidal elevations / current time series in sections through region
- Forecast current fields through region
- No Nodal Wind Speed input
- Runs on PC



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# ADCIRC - Advanced Circulation Model

RMA2 - Resource Management Associates (USACE contract)

WQMAP - Water Quality Management and Analysis Package (ASA)



REGIONAL		YEAR	2005	2006	2007	2008	2009	2010	2011
ADCIRC 2D Barotropic	u	3 AREAS							
ADCIRC 3D Barotropic	u	5 AREAS							
ADCIRC 3D Barotropic	c	6 AREAS							
ADCIRC Baroclinic	u	3 AREAS							
ADCIRC Baroclinic	c	3 AREAS							
WQMAP / HYDROMAP	u/c	10 AREAS							
RAM2	u/c	11 AREAS							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- By 2008, **ADCIRC** will be a fully baroclinic 3D coastal model
  - Up to 9 domains that can be quickly deployed, depending on bathymetry.
- In addition to ADCIRC, NAVOCEANO has installed and is successfully using rapidly implementable,
  - RMA-2** - a 2D, finite element, barotropic model
  - WQMAP / HYDROMAP** - for nearshore and coastal circulation predictions.

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# Global

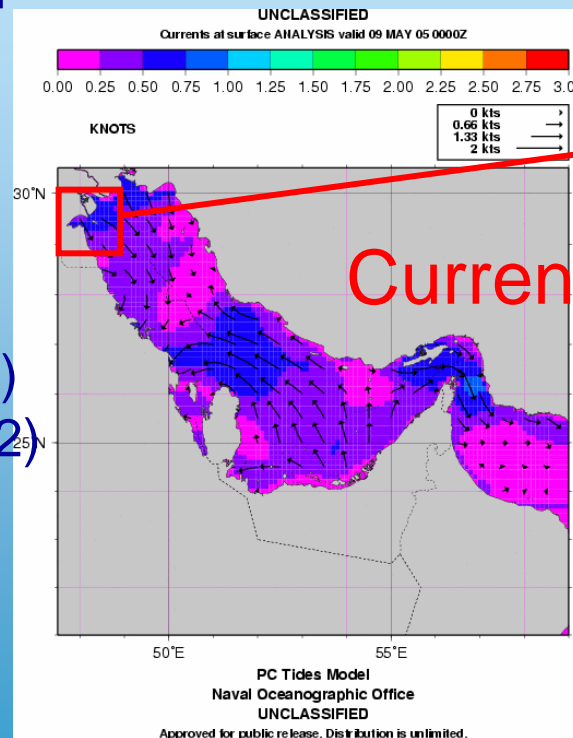
# Regional

# Local

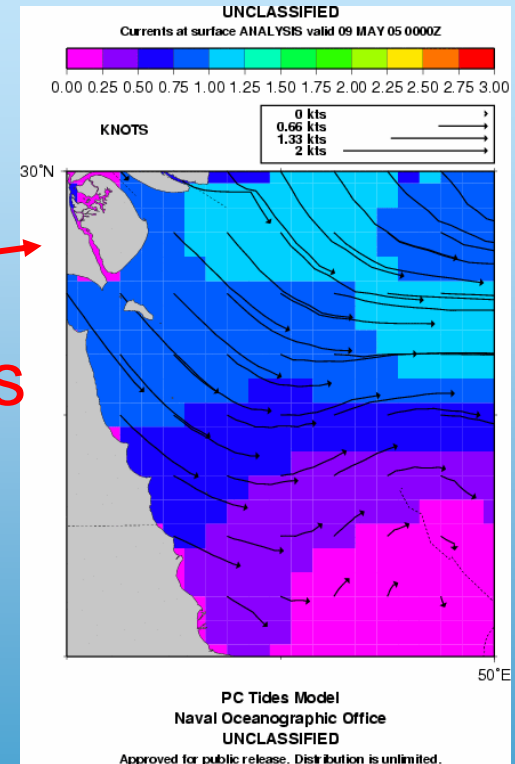


## PC TIDES

- Application of wave equation
- 2D barotropic model
- Forced by tidal stations & FNMOC / local winds
- Tidal elevation & currents
- Assimilates nearby tidal stations (4000+ IHO stations)
- 2-minute bathymetry (DBDB2)
- Nest to needed resolution
- Provides a first guess - rapid implementation (24 hours)
- 2D graphics, time series, constituent table outputs
- Hurricane storm surge module



Currents



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# PCTIDES - Advanced Circulation Model

RMA2 - Resource Management Associates (USACE contract)  
WQMAP - Water Quality Management & Analysis Package (ASA)

TIDES		YEAR	2005	2006	2007	2008	2009	2010	2011
PCTIDES	u	10 AREAS							
PCTIDES	c	30 AREAS							
MSRC		gigaflops	22	36	50	50	50	50	50
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- Elevations available from SWAFS and NCOM with OSU (Egbert / OTIS) model
- PCTIDES undergoing OPEVAL in CY2005.
  - A proposed upgrade is planned by CY2007.
- RMA2 and WQMAP can also provide tidal elevation and 2D current forecasts

Global

Regional

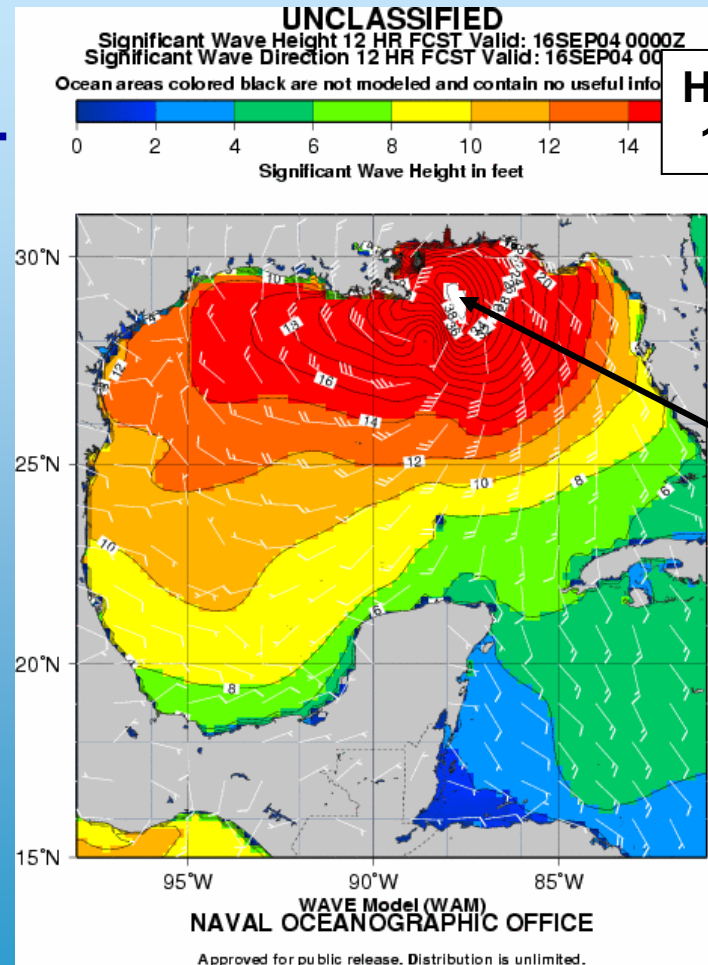
Local



## WAVE ANALYSIS MODEL WAM

- Portable - easily relocated
- Variable resolution ( $1/4^\circ$  to  $1/12^\circ$ )
- Forecast to 72 hours (2x daily)
- Forced by FNMOC model winds
- Deep water (  $> 20$  m )
- Gridded set of wave parameters
  - Significant wave height & direction
  - Sea & swell wave height, direction, period
  - Wave energy spectra by direction & period

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Hurricane IVAN  
16 SEPT 2004

> 40 ft



# Global

# Regional

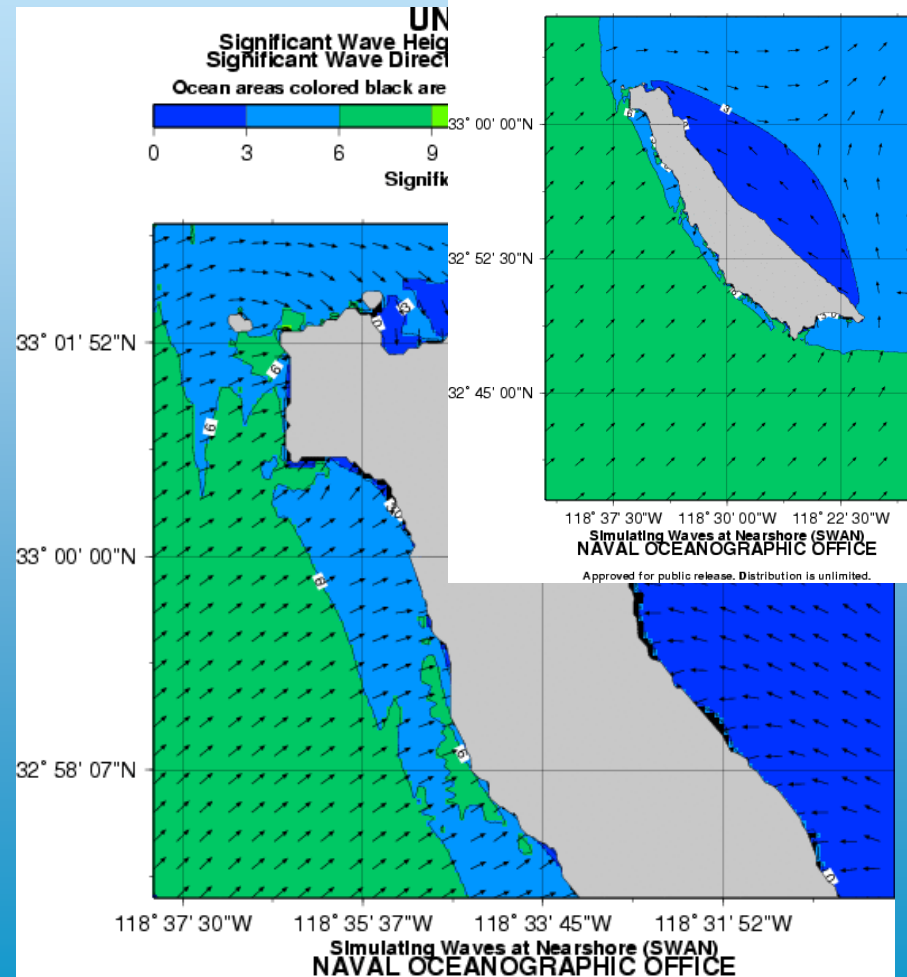
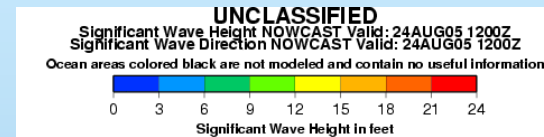
# Local



## SIMULATING WAVES NEARSHORE - SWAN

- Part of U. Delft DELFT3D package
- A 3<sup>RD</sup> generation stand-alone (phase-averaged) wave model to simulate waves in waters of deep, intermediate and finite depth
- Forecasts wave properties into surf zone
- Transitioned to NAVO FY05
- Resolutions from regional (1/12 deg) to beach (~10 m)
- Deliver graphics, data (NetCDF properties similar to WAM)

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# WAM - Wave Model

## WW3 - Wave Watch 3

### SWAN - Simulating Waves Nearshore



WAVES & SURF		YEAR	2005	2006	2007	2008	2009	2010	2011
WAM	U	40 AREAS			--> WW4+				
WW4+	U	GLOBE+10							
SWAN	U	15-->25							
SWAN	C	10-->30							
STWAVE	U	~10		--> SWAN					
NSSM	U	~10							
DELFT3D	U/C	20 AREAS							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
							OPERATIONAL		

- NAVOCEANO runs the spectral **WAM** model twice daily
  - Approximately 40 nested domains.
  - A placeholder for a **Wave Watch-4+** upgrade COULD receive from USACE CY2006
  -
- **SWAN** is being transitioned to NAVOCEANO during CY2005
- **DELFT3D**, incorporating SWAN, coastal flow, and surf modules, starts transition CY2006

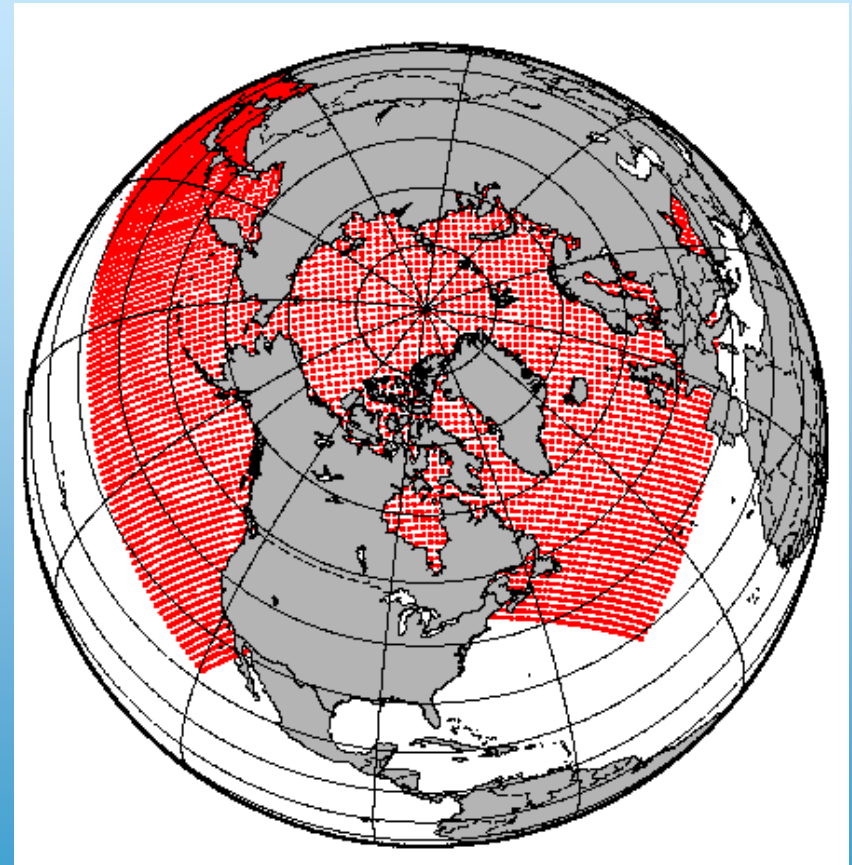
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# Polar Ice Prediction System - PIPS 2.0



- Coupled Ice-Ocean Model (Hibler/Cox)
- Includes all sea ice covered regions of the northern hemisphere
- 0.28 degree ( $\sim 1/4$ ) grid resolution
- 15 vertical levels
- Solid wall boundaries
- Ocean loosely constrained to Levitus climatology
- Transitioned to NAVO in FY04
- Operational Oct 2004 – on Cray Sv (Poseidon)
- Converted code from CRAY to IBM (Kraken) June 2005



Hatched lines every 4<sup>th</sup> grid point

# PIPS - Polar Ice Prediction System



ICE		YEAR	2005	2006	2007	2008	2009	2010	2011
PIPS 2.0	u	ARCTIC							
PIPS 3.0 (G-NCOM)	u	ARCTIC							
PIPS 3.0 (G-HYCOM)	u	ARCTIC							
MSRC		gigaflops	3	3	2	17	17	17	17
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- PIPS 2.0 was transferred from FNMOC to NAVOCEANO during CY2004.
  - The upgrade PIPS 3.0, based on the Los Alamos CICE algorithms, is being installed as part of the NCOM/HYCOM suites.

# Summary



- NAVOCEANO modeling system designed to meet Navy needs
  - Span global – regional – local domains
  - Variety of models / products
  - Daily update production
- MSRC is a capable engine
  - Biennial upgrades will allow hosting of high resolution 1/24 degree HYCOM
- HYCOM will be our global & regional model of the future
- Interests from the HYCOM meeting
  - Product assessment tools
  - Latest on data assimilation

# NAVOCEANO Modeling Information Matrix



## DIMENSIONS

Horizontal (x,y)

Deep water, coastal, shallow, estuary, transitions

Regular grid, curvilinear, finite element

Vertical (z)

2D, 3D / Constant depth, sigma levels, hybrid

Time (tau)

Climate, history, analysis, daily, hourly (tidal), forecast length

## PROPERTIES

Elevations

Tides

Currents

[U,V], [speed,direction], average, instant, drift, dispersion

Temperature & Salinity

Density & sound speed, ASW properties (MLD, SLD, DSCA, etc.), water masses, river runoff

Waves & Surf

Significant, swell, height, direction, period, surf parameters

Relevant processes

Surface layer, thermocline, deep water, ocean currents, fronts & eddies, internal waves, geostrophy, thermohaline

## FORCING

Bathymetry

None, canned, bad / smooth, coastal, irregular, time varying

Atmosphere

None (tides), global-local / winds, pressure, air-sea exchanges

Other

Gravity, altimetry, tides, friction, parameterization

Boundaries

Nesting levels, surface, 2D, steady-state / time variable